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The Correlation of Soil Tests with Yield Response and Uptake of Phosphorus by Barley

Anthony Unusa Salami

THE CORRELATION OF SOIL TESTS WITH YIELD
RESPONSE AND UPTAKE OF PHOSPHORUS
BY BARLEY

BY
ANTHONY UNUSA SALAMI

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THE CORRELATION OF SOIL TESTS WITH YIELD

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BY BARLEY

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Agronomy Department Date

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INTRODUCTION

This study has stemmed from the results of a number of fertilizer experiments conducted by Carson _et al_. (12, 31) with spring wheat on Chestnut soils in the North Western part of South Dakota. Results of experiments with phosphorus conducted on non-fallowed land during the years 1961 through 1964 showed that added phosphorus produced a higher percentage yield increase on soils having a low phosphorus soil test as determined by modified Bray No. 1 method (11) than on soils with high P. On the other hand, the yield increases from added phosphorus on fallowed land have not been as related with soil tests as on non-fallowed land. A greater yield increase was obtained from added phosphorus on soils with a high P soil test than a medium soil test.

The purpose of this study was to examine some of the soil test methods and relate them to yield response and phosphorus uptake by plants on chestnut soils. For uptake of phosphorus studies, the quick uptake method proposed by Stanford and DeMent (34) was used. The method as proposed does not fully take care of moisture control problems. It was hoped, therefore, that by using the moisture control apparatus proposed by Waugh and Corey (40) for quick uptake studies, it would be possible to fully maintain uniform moisture in the soils during the growth period of the plants and thus increase the precision of the experiment.

REVIEW OF LITERATURE

Correlation of Soil Tests with P Uptake

The reliability of various soil test methods for estimating available P has received considerable study among soil scientists. The use of 0.03N NH_4F and 0.025N HCl proposed by Bray and Kurtz (11) has, for some time, been the object of numerous correlation studies. Thompson and Pratt, (37) working in Ohio, subjected 18 soil samples belonging to 14 soil series to greenhouse cropping with alfalfa and corn and to various extractant solutions for measurement of available P and found that Bray No. 1 solution correlated well with plant available P.

MacLean *et al.* (25) working on some New Brunswick soils using Ladino clover as test crop found that Bray No. 1 P gave a highly significant correlation coefficient with plant uptake of P.

Smith *et al.* (32) have found that the use of Bray No. 1 with a soil to solution ratio of 1 to 50 was a better estimate of the available P than a ratio of 1 to 70 or any of the other extractants he used on calcareous soils. He postulated that a higher ratio provided enough H^+ to react with excess $CaCO_3$ present in calcareous soils. This work was done on calcareous soils from western Kansas.

The use of 0.5N $NaHCO_3$ has been proposed by Olsen et al. (29) as a suitable extractant because it has been found to correlate well with plant available P and "A" values. They demonstrated that a good relationship exists between the expected crop response in the field and the level of P soluble in $NaHCO_3$. These workers also found that Bray No. 1 and water extractants correlated well with "A" value. Thompson and Pratt (37) have found similar results with 0.5N $NaHCO_3$ solution. They indicated that the solution extracted amounts of P that were an accurate estimate of plant available P.

Bouldin and Sample (7) in a greenhouse and laboratory study in Alabama with monocalcium, monoammonium, and diammonium phosphates on fine sandy loam and silty clay loam soils, found that approximately 85% of the variation in plant uptake of P with different fertilizers in greenhouse experiments was explained by the measurements in the laboratory of water-soluble P around the pellet.

Morgan (27) proposed a method for estimating available P using 10% solution of sodium acetate in 3% acetic acid, and strongly buffered at a pH of 4.8. Ghani and Aleem (19) in their fractionation studies, have indicated that the method proposed by Morgan extracted mono-, di-, and tricalcium phosphates.

Phosphorus uptake from calcareous and noncalcareous soils were correlated with available P as determined with five extractants by Blanchar and Caldwell (6) in Minnesota. Their results showed that all extractants, with the exception of Bray No. 1 with soil to solution ratio of 1 to 10, correlated well with P uptake on calcareous soils. The relationships with P uptake, however, were not as close with Exchange Resin and $NaHCO_3$ methods. On noncalcareous soils, all extractants correlated with P uptake. However, Exchange Resin and Bray No. 1 with soil to solution ratio of 1 to 50 were not as closely related to P uptake as were other extractants. The P obtained with water and Morgan extractants accounted for over 90% of the variation in plant uptake of P. These workers used the quick uptake method proposed by Stanford and DeMent (34).

The use of 0.3N NaOH + 0.5N $Na_2C_2O_4$ solution has been proposed by Al-Abbas and Barber (2). These workers fractionated twenty-four soils from Indiana to determine the forms of P. Their results showed that Fe-P explained most of the variation (1). In subsequent work based on results of the fractionation studies, the authors proposed a new soil test method using 17 milliliters of 0.3N NaOH and 3 milliliters of 0.5N $Na_2C_2O_4$ for 1 g of soil. They contend that the method works particularly well for soils of pH>7.

Susuki *et al.* (36) determined available P on 17 samples of surface soils from Michigan and each soil was cropped in the greenhouse with barley for four weeks to determine the P uptake and "A" values. Correlation analysis showed that Truog P was highly correlated with short term uptake while "A" values were highly correlated with Olsen, Exchange Resin and Bray P. They further showed that Fe-P and organic P did not contribute to the phosphorus removed by any of the measurements. Truog P apparently removed portions of both the Ca-P and Al-P and the P removed by the cropping was said to be derived from Al-P and Ca-P. All other measurements were highly correlated with only Al-P.

Correlation of Soil Tests with Yield Response

The relationships between yield response and soil test methods have been investigated by a number of workers. Mitscherlich (26) formulated an equation for determining the response of a crop to several increments of a given nutrient. Bray (8, 9) in his studies on a number of crops with potassium and phosphorus, found that the correlation between the amounts of the available forms and percentage yield (where the yield on the adequately treated plots is taken as 100 percent) gave a curve that was similar to the Mitscherlich growth curve. He pointed out, however, that the original Mitscherlich equation did not adequately take care of the forms of phosphorus and potassium that were measured directly by soil tests. Consequently, he proposed a modified Mitscherlich equation to contain the term x (the fertilizer added). Using the modified equation, he obtained high correlation between the amounts of the available forms as extracted by Bray's method and the yield response calculated as percentage yield.

Arnold and Schmidt (3), from data collected from 25 field experiments carried out primarily in Illinois, have demonstrated that Bray's method of phosphorus soil test correlated with the response of tomatoes to phosphate fertilizer. Best correlations were obtained when soil tests were compared with the yield of unphosphated soil computed as a percentage of the yield on soil when adequately phosphated. They further showed that productivity level, length of season, or forms of soil phosphorus present were not found to be associated with significant changes in the correlations. Heeney and Bishop (21) in a similar study with tomatoes as a test crop, designed to establish correlation tables between phosphorus soil test values and crop response to phosphate fertilizer, and using the modified Mitscherlich equation as proposed by Bray (8), indicated that Bray's method of soil analysis provides a reliable index of the phosphorus status of the soil and hence may be used to predict the relative yield increases to be expected from the use of phosphatic fertilizer.

On the contrary, studies conducted by Larson _et al_. (23) at Indiana on organic soils with seven extractant solutions indicated that distilled water extracts gave the most accurate estimates of plant available P in the ratio of soil volume to extracting solution of 1:20 for organic soils, and 1:10 for mineral soils. Both Bray # 1 and # 2 extractants were found to give nonsignificant correlation coefficient values with percentage yield.

Welch, Ensminger and Wilson (41), in a study with three soil types which represent large acreages in Alabama, and using Ladino clover as a test crop, obtained high correlation coefficients between soil test methods and yield response computed as percentage yield. His extractants were 0.05N HC1 + 0.025N H_2SO_4 (used in Alabama soil testing laboratory), 0.5M $NaHCO_3$ proposed by Olsen _et al_. (29) and 0.03N NH_4F + 0.1N HC1, proposed by Bray and Kurtz (11). Consequently, these workers contended that all the above soil testing methods could be used satisfactorily as a basis for making phosphorus recommendations.

The effects of soil phosphorus compounds on soil test correlations have been studied by Bishop and Barber (4) in Indiana. These workers found that calcium phytate and other organic phosphorus compounds are partially soluble in acid extractants, thus suggesting that an acid extraction contains phosphorus from both organic and inorganic sources. This was supported by the fact that significant correlation was obtained between organic matter and acid soluble phosphorus.

Semb and Steenberg (30) in a comparative study of the different chemical and isotopic methods for the estimation of soil content of plant available P in Norway, found that there was good correlation between available P as determined by the Olsen method (29) and yield responses. The best correlation was, however, obtained for the group of soils with a pH $\geq$ 6.3.

Bray and Dickman (10) in their adsorption studies, indicated that certain fractions (fractions 1 and 2) of the adsorbed phosphates were important for plant response. High amounts of these fractions would result in low response no matter how much of other fractions were present in the soil.

Bray (9) has indicated that to be successful, a soil test must fulfil three requirements. First, it must extract the total or proportionate amounts of the available form of the nutrient from soils with variable properties. Second, it must measure with reasonable accuracy the amounts of the nutrients in the extract; and finally, its action must be fairly rapid. Accuracy, not withstanding, should not be sacrificed for speed.

A good correlation between soil test methods and yield response and/or uptake of P shows the degree of co-relationship and therefore, the degree to which the above requirements are met; especially the first requirement.

It was the purpose of this study to correlate the available P obtained from some standard soil test methods with yield response, and uptake of P with a view to determining the degree to which these variables relate.

MATERIALS AND METHODS

The soils used for this study were Chestnut soils. Chestnut soils are zonal soils that have developed in temperate, semi-arid climates under mid and short grass vegetation in the absence of ground water influence. Base saturation of these soils is usually greater than 90 percent (18, 42).

Collection of Soil Samples

Bulk samples of Chestnut soils derived from three parent materials; namely, residual, loess and till, and belonging to six soil series, were collected during the fall of 1965. The soil samples were taken from the plow layer and were obtained from thirty sites representing the major agricultural soils in the Chestnut area of South Dakota. See Figure 1.

The county, site, great soil group, family and series of these soils are given in Table 1.

Of these thirty samples, ten were derived from each of the three parent materials. Part of each soil sample was then air dried and screened. A portion of the airdried sample was used for chemical analysis in the laboratory while the other part was used for quick-uptake studies in the greenhouse. The other part of the sample in moist condition was used for yield response studies in the greenhouse.

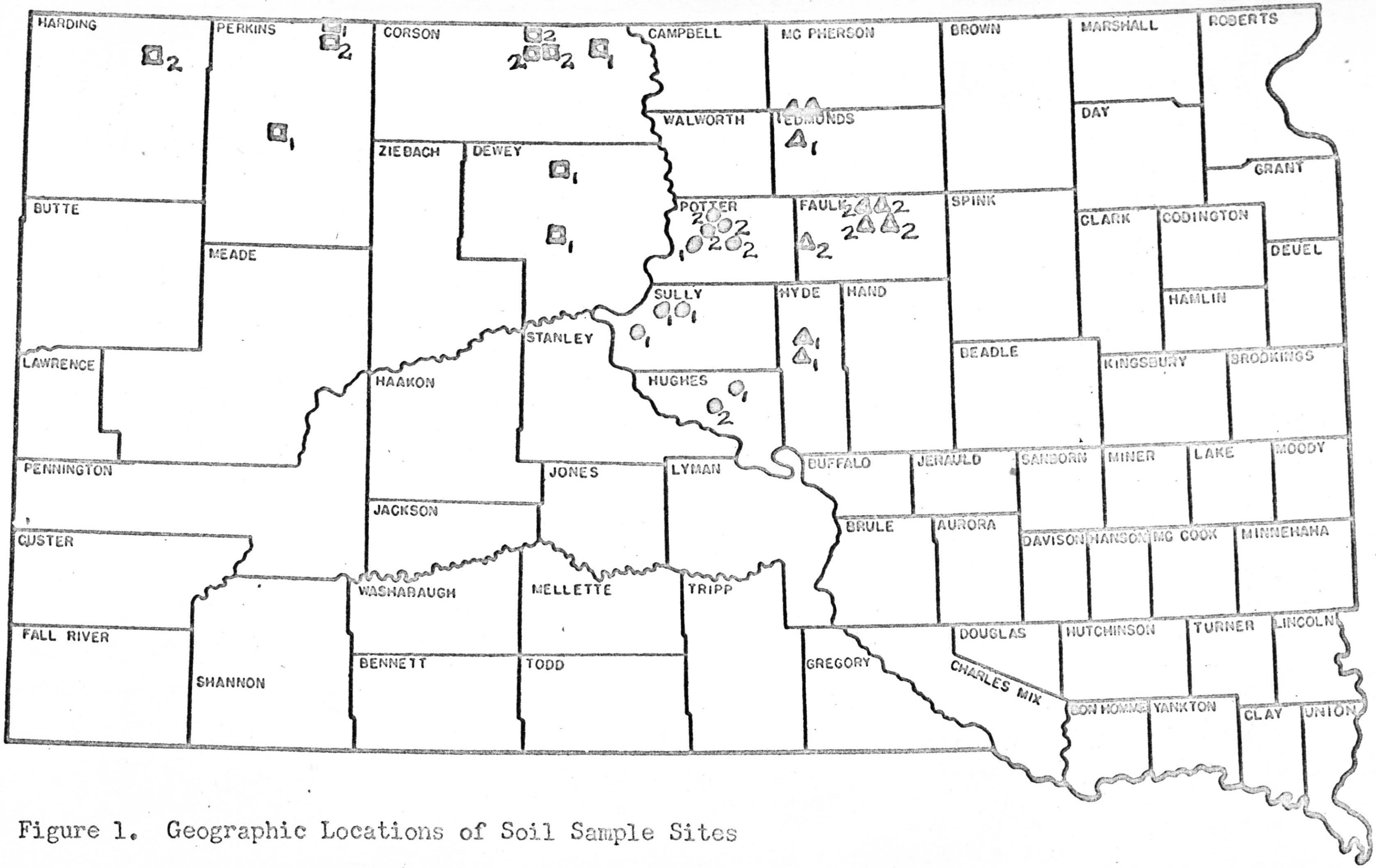

Figure 1. Geographic Locations of Soil Sample Sites

□1,2 Residual Soils 1. Morton
2. Regent

○1,2 Loess Soils 1. Agar (level)
2. Agar (sloping)

△1,2 Till Soils 1. Williams
2. Cresbard

Table 1. Classification of Soils Under Study Using 7th Approximation (39)

Parent Material	County	Site	Great Soil Group	Family	Series
Residual Soils	Dewey	Dosch	Typic Argiustoll	Fine silty mixed mesic	Morton
Residual Soils	Dewey	Lutz	Typic Argiustoll	Fine silty mixed mesic	Morton
Residual Soils	Perkins	Veal	Typic Argiustoll	Fine silty mixed mesic	Morton
Residual Soils	Harding	Knudsen	Typic Argiustoll	Fine mixed frigid	Regent
Residual Soils	Perkins	Mitchell	Typic Haplustoll	Coarse loamy mixed frigid	Morton
Residual Soils	Perkins	Mitchell N.	Typic Argiustoll	Fine mixed frigid	Regent
Residual Soils	Corson	Farstad '61	Typic Argiustoll	Fine mixed frigid	Regent
Residual Soils	Corson	Farstad '62	Typic Argiustoll	Fine mixed frigid	Regent
Residual Soils	Corson	Farstad '63	Typic Argiustoll	Fine mixed frigid	Regent
Residual Soils	Corson	Young G.	Typic Argiustoll	Fine silty mixed mesic	Morton

Table 1. Continued.

Parent Material	County	Site	Great Soil Group	Family	Series
Loess Soils	Hughes	Stewart	Typic Argiustoll	Fine silty mixed mesic	Agar (0-2%)
Loess Soils	Sully	Jim Young	Typic Argiustoll	Fine silty mixed mesic	Agar (0-2%)
Loess Soils	Potter	Nauman	Typic Argiustoll	Fine silty mixed mesic	Agar (0-2%)
Loess Soils	Sully	Lyons (W)	Typic Argiustoll	Fine silty mixed mesic	Agar (0-2%)
Loess Soils	Sully	Lyons (E)	Typic Argiustoll	Fine silty mixed mesic	Agar (0-2%)
Loess Soils	Hughes	Hauschild	Typic Argiustoll	Fine silty mixed mesic	Agar (2-6%)
Loess Soils	Potter	N. of Gettysburg	Typic Argiustoll	Fine silty mixed mesic	Agar (2-6%)
Loess Soils	Potter	W. of Gettysburg	Typic Argiustoll	Fine silty mixed mesic	Agar (2-6%)
Loess Soils	Potter	N.W. of Gettysburg	Typic Argiustoll	Fine silty mixed mesic	Agar (2-6%)
Loess Soils	Potter	N.W. of Gettysburg (eroded)	Typic Argiustoll	Fine silty mixed mesic	Agar (2-6%)

Table 1. Continued.

Parent Material	County	Site	Great Soil Group	Family	Series
Till Soils	Hyde	Highmore* range 200 (0-0-0)	Typic Argiustoll	Fine loamy mixed frigid	Williams
Till Soils	Hyde	Highmore* range 200 (0-40-0)	Typic Argiustoll	Fine loamy mixed frigid	Williams
Till Soils	Edmunds	Hosmer (S)	Typic Argiustoll	Fine loamy mixed frigid	Williams
Till Soils	Edmunds	Hosmer (S.W.)	Typic Argiustoll	Fine loamy mixed frigid	Williams
Till Soils	Edmunds	Jung	Typic Argiustoll	Fine loamy mixed frigid	Williams
Till Soils	Faulk	Bergerson	Glossic Natriboroll	Fine mixed	Cresbard
Till Soils	Faulk	Norbeck (N)	Glossic Natriboroll	Fine mixed	Cresbard
Till Soils	Faulk	Norbeck (N.E.)	Glossic Natriboroll	Fine mixed	Cresbard
Till Soils	Faulk	Norbeck (N.W.)	Glossic Natriboroll	Fine mixed	Cresbard
Till Soils	Faulk	Norbeck (W)	Glossic Natriboroll	Fine mixed	Cresbard

* Soils from experimental station

GREENHOUSE STUDIES

Yield Response Studies

Moisture retention by the soils at field capacity was determined with the pressure cooker and pressure membrane apparatus as outlined in USDA Agriculture Handbook No. 60 (38). No. 10 tin cans were washed, dried and lined with polyethylene bags to prevent moisture losses. In each can was put 1,000 g of sand, followed by 1,000 g of test soil (oven dry basis), and finally 1,000 g of sand, giving a total of 3,000 g with the test soil forming an interlayer between the two sand layers. Eight such cans received soils from one site, giving a total of 240 cans for the thirty soil samples from thirty sites. Of the 240 cans, 120 cans received phosphorus fertilizer at the rate of 90 lbs. of P per two million lbs. of soil. The other 120 cans did not receive phosphorus. In addition, all cans received N and K fertilizer; each receiving 132 lbs. of N and 100 lbs. of K per two million lbs. of soil in the form of NH_4NO_3 and KCl, respectively. All nutrients were applied in solution form. All soils were brought to field capacity by the addition of distilled water. Each can was then planted with 30 barley (variety Larker) seeds, selected for uniformity of size, and later thinned to 24 seedlings per can.

Additional nitrogen nutrient solution was applied at the rate of 76 lbs. of N per two million lbs. of soil during the growth period.

After eight weeks of growth, the plants were harvested, oven dried at 65° C. and weighed. Yield responses as percentage yield were determined on dry matter basis.

A simple, completely randomized design with four replications was used for this experiment. Each replicate consisted of 60 cans (30 cans with P and 30 without P). Two cans (one can with P and one can without P) received soils from the same site, thus giving 60 cans for the 30 sites. These were randomized within each replication. (14, 35)

Quick Uptake of P Experiment

Growth of Plants for P Absorption Studies

Forty round cardboard cartons of 12-ounce capacity with bottoms removed were nested in identical containers with bottoms intact and filled with 680 g of sand, as outlined by Stanford and DeMent (34). Forty barley seeds, selected for uniformity of size, were planted at 3/4" depth and later thinned to 30 seedlings per carton. Ten milliliters of a minus P nutrient solution was added to each carton, supplying 200 mg of N and 100 mg of K as NH_4NO_3 and K_2SO_4 respectively. Traces of Zn, Fe, Mn, Mg and B were also supplied. In addition, 90 milliliters of distilled water were added, giving a total of 100 milliliters of liquid per carton. Additional minus P nutrient solution was supplied during the 17-day growth period.

Moisture Control Apparatus

The moisture control apparatus proposed by Corey and Waugh (38) for short term uptake studies was used for this experiment. Three circular 12 pot holders were constructed, each placed on an iron rod with a flat base. A plastic reservoir was constructed for each 12 pot holder in such a way that the reservoirs were placed directly below the pot holders.

A 5-inch beveled Alundum filter disc was seated into a 6-inch glass funnel using rubber cement. This was then sealed with several coats of Durkee Atwood liquid adhesive applied to class-Alundum junction. After the seal had set, tygon tubing was attached to the funnel, and the entire assembly and the reservoir were filled with distilled water. See Figure 2.

P Uptake Studies

A carton with the bottom removed was placed on the funnel and filled with 200 g of air-dried test soil. The soil was then allowed to equilibrate for a few hours. The carton containing the P-deficient plants was nested in the carton holding 200 g of test soil, thus placing the mat of roots in intimate contact with the soil. See Figure 3.

There was a mat of roots in the soils after a few days of root-soil contact. See Figure 4.

After seven days of root-soil contact, the tops were excised from the seeds, oven dried at 65° C and weighed. They were then ground to pass through a 40 mesh screen in a micro-Wiley mill. Phosphorus content of the plant material was determined.

A simple, completely randomized design was used with five replications. The 30 soil samples from 30 sites constituted a replicate (10 on each 12-pot holder). The replicates were run at different times due to limited equipment and space. (14, 35)

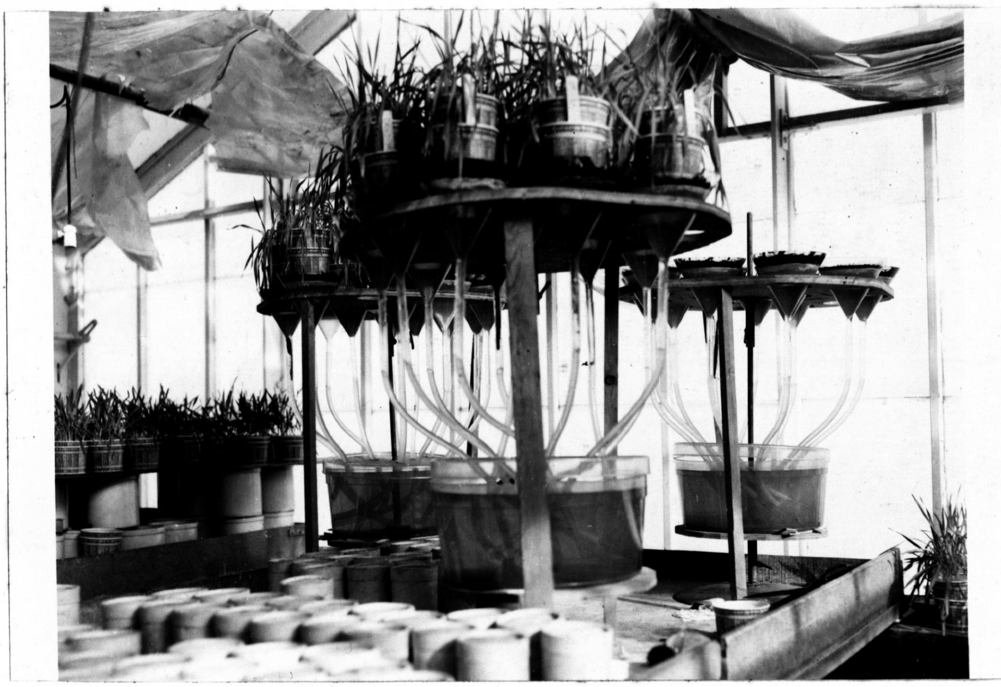

Figure 2. Short term moisture control apparatus.

Figure 3. Placement of the rootmat of P. deficient plants in contact with soil.

Figure 4. Root distribution in test soil after seven days of root soil contact.

LABORATORY STUDIES

The air dried soils for this study were ground to pass through a 2 mm sieve.

Soil Test Methods

Five soil test methods were used for this study. The procedures were as follows:

Bray No. 1 (11) This test consists of shaking 2 g of soil with 20 ml of 0.03N NH_4F + 0.025 N HCl for 5 minutes, removal of filtrate by filtration and the determination of P colorimetrically. This gives a soil to solution ratio of 1:10.

Bray No. 1 (1:50) This consists of shaking 1 g soil with 50 ml of Bray No. 1 solution as above and determination of P colorimetrically using the method of Dickman and Bray (17).

The Olsen test (29) consists of shaking 2 g of soil with 40 ml of 0.5N $NaHCO_3$ solution adjusted to a pH of 8.5 with NaOH for 30 minutes and filtering. The P in the extract was determined by the ascorbic acid method proposed by Murphy and Riley (28). The intensity of the color was read at 690 mu using the blue filter.

The Morgan test (27) consists of shaking 10 g of soil plus $\frac{1}{4}$ teaspoonful of activated charcoal with 50 ml of the extracting solution composed of 0.73N $NaC_2H_3O_2 \cdot H_2O$ in 0.52N acetic acid for 30 minutes, filtering and determining the

P in the extract colorimetrically using the method outlined by Greweling and Peech (20).

The Barber test (2) consists of shaking 1 g of soil with 20 ml of solution made up from 17 ml of 0.3N NaOH and 3 ml of 0.5N $Na_2C_2O_4$, for 5 minutes, and filtering. The P in the extract was determined colorimetrically using the method of Dickman and Bray (17).

The water test was determined by shaking 5 g of soil with 50 ml of deionized water for 5 minutes, filtering and determining the P colorimetrically using the ascorbic acid method outlined by Murphy and Riley (28).

Nutrient Status

Percent organic matter, salts, available P, and exchangeable K were determined by the South Dakota State University Soil Testing Laboratory. Soil pH was measured on a 1:1 soil to water paste as outlined by Jackson (21). The texture was determined by the method outlined by Lunt *et al.* (24).

Determination of P in Plant Material

The ground plant material was dried for 24 hours at 65° C and 0.1 g of plant tissue was used for the analysis. The procedure used was a method modified by Blanchar (5) of the vanadomolybdophosphoric-yellow color method outlined by Jackson (22). The intensity of the color was read on the Junior Coleman Spectrophotometer at 430 mu.

Statistical Method

The data from both yield response experiment and the quick uptake experiment were used to run simple linear correlations with the estimates of available P obtained with the five extractants on all soils. These informations were grouped according to

(1) Parent materials,

(2) pH, and

(3) Texture.

The following linear correlations were also determined

(1) Between soil test methods and

(2) Between uptake of P and yield response.

The purpose of running these correlation studies was to determine the relationships of the variables when the soils under study were considered on the basis of parent material, pH, and texture.

RESULTS

Routine laboratory analyses were conducted on the soil samples with a view to characterizing some of the properties of the soils. Table 2 shows some of the properties of the soils under study.

As indicated in Table 2, most of the soils have a pH less than 7 and relatively few soils have a pH above 7. Although the data show a trend of slight acidity in the surface soil, the subsoils are calcareous.

The percent organic matter in the soils ranges from as low as 1.7 to as high as 3.5.

In terms of available nitrogen based on percent organic matter, some of the soils are low in their ability to supply adequate nitrogen for plant needs.

The estimates of available P range from as low as 6 lbs./A to as high as 74 lbs./A.

The exchangeable K, on the other hand, is quite adequate in terms of plant needs in all soils. The soils are well supplied with exchangeable K.

The salt concentration for all soils is low and is not likely to have any deleterious effects on the growth of the plants.

Table 2. Some Properties of the Soils Under Investigation

Sample No.	Site	Texture	Salts* Ec x 10^3	Organic Matter %	P Lbs/A	K Lbs/A	pH 1:1 Soil Paste
	Residual Soils						
1	Dosch	Loam	.31	2.1	13	533	7.3
2	Lutz	Silt loam	.75	1.9	59	533	6.0
3	Veal	Silt clay loam	.34	1.8	36	527	6.5
4	Knudsen	Silt clay loam	.27	1.7	19	430	6.7
5	Mitchell	Loam	.20	1.8	36	467	6.6
6	Mitchell (N)	Loam	.20	1.9	43	489	6.2
7	Farstad '61	Silt loam	.22	1.7	32	373	7.1
8	Farstad '62	Silt clay loam	.26	2.3	50	533	6.8
9	Farstad '63	Silt clay	.34	2.3	43	533	6.5
10	Young G.	Silt clay loam	.23	2.3	41	533	6.4
	Loess Soils						
11	Stewart	Loam	.25	3.1	31	533	6.8
12	Young J.	Loam	.31	3.0	25	533	7.1
13	Nauman	Loam	.28	2.6	27	533	7.3
14	Lyons (W)	Loam	.29	2.7	32	533	6.5
15	Lyons (E)	Silt clay loam	.26	1.8	24	533	6.8
16	Hauschild	Silt loam	.24	2.4	29	533	7.2
17	North of Gettysburg	Silt loam	.23	1.8	6	319	7.8
18	West of Gettysburg	Silt loam	.25	2.1	9	367	7.7
19	N.W. of Gettysburg	Silt loam	.25	2.2	16	533	6.5
20	N.W. of Gettysburg (eroded)	Silt loam	.23	2.0	8	348	7.0

Table 2. Continued.

Sample No.	Site	Texture	Salts* Ec x 10^3	Organic Matter %	P Lbs/A	K Lbs/A	pH 1:1 Soil Paste
	Till Soils						
21	Highmore range 200 (0-0-0)	Silt clay loam	.20	2.6	68	430	6.7
22	Highmore range 200 (0-40-0)	Silt clay loam	.24	2.5	74	457	6.5
23	Hosmer (S)	Silt loam	.27	2.1	18	383	7.7
24	Hosmer (S.W.)	Silt clay loam	.25	2.6	11	435	6.8
25	Jung	Silt clay loam	.20	2.5	18	451	7.3
26	Bergerson	Silt clay loam	.36	2.4	48	533	6.6
27	Norbeck (N)	Silt clay loam	.22	2.7	22	533	6.4
28	Norbeck (N.E.)	Silt clay loam	.19	3.1	41	533	6.3
29	Norbeck (N.W.)	Silt clay loam	.26	3.2	20	533	6.4
30	Norbeck (W)	Silt clay loam	.24	3.5	35	533	7.0

* Soluble salts in millimhos/cm

Yield Response Experiment

The yields on dry matter basis, and the yield responses calculated as percentage yield are given in Table 3. The percentage yield was calculated as follows:

$$\text{Percentage yield} = \frac{\text{Yield of unphosphated x 100}}{\text{Yield of adequately phosphated}}$$

As indicated in Table 3, the yields were quite variable but there were consistent yield increases from applied phosphate.

Yield Response Experiment and Soil Test Values

The soil test values for the various extraction methods calculated on parts per two million basis are given in Table 4. Also included are the relative values of yield responses calculated as percentage yield. The data in Table 4 show that the soils differed in the amounts of extractable P. More P was extracted by Barber, Morgan, and Bray No. 1 (1:50); than by Bray No. 1 (1:10), Olsen, and water. On the average, till and residual soils had higher available P values. For all soils, the lowest amounts of available P were obtained with water as an extractant. The yield responses, on the average, for till soils were slightly higher than those of residual and loess soils. Residual and loess soils had about the same average yield response.

Table 3. Yield in Grams on a Dry Matter Basis and Percentage Yield per Pot

Site	Sample No.	Total Wt. in Gm/4 Pots Minus P	Total Wt. in Gm/4 Pots Plus P	Mean Wt. in Gm/Pot Minus P	Mean Wt. in Gm/Pot Plus P	Percentage Yield *
Residual Soils						
Dosch	1	18.71	29.01	4.68	7.25	64.5
Lutz	2	29.34	32.97	7.34	8.24	89.0
Veal	3	25.79	34.28	6.45	8.57	75.2
Knudsen	4	18.82	36.92	4.71	9.26	51.1
Mitchell	5	24.88	32.57	6.22	8.14	76.4
Mitchell N	6	25.60	30.31	6.40	7.58	84.5
Farstad '61	7	27.82	34.27	6.96	8.57	81.2
Farstad '62	8	29.39	37.73	7.35	9.43	77.9
Farstad '63	9	29.74	35.62	7.44	8.91	83.5
Young G	10	28.22	33.68	7.06	8.42	83.8
Loess Soils						
Stewart	11	25.78	32.76	6.45	8.19	78.7
Young, Jim	12	32.20	39.50	8.05	9.88	81.5
Nauman	13	28.18	33.36	7.05	8.34	84.5
Lyons (W)	14	33.40	41.00	8.35	10.25	81.5
Lyons (E)	15	28.55	32.29	7.14	8.07	88.4
Hauschild	16	24.17	28.87	6.04	7.22	83.7
N. of Gettysburg	17	15.29	21.92	3.82	5.48	69.8
W. of Gettysburg	18	20.02	25.29	5.01	6.32	79.2
N.W. of Gettysburg	19	28.87	40.20	7.22	10.05	71.8
N.W. of Gettysburg (eroded)	20	16.61	27.07	4.15	6.77	61.4

Table 3. Continued.

Site	Sample No.	Total Wt. in Gm/4 Pots		Mean Wt. in Gm/Pot		Percentage Yield *
		Minus P	Plus P	Minus P	Plus P	
<u>Till Soils</u>						
Highmore range 200 (0-0-0)	21	24.10	28.30	6.03	7.08	85.2
Highmore range 200 (0-40-0)	22	36.68	37.27	9.17	9.32	98.4
Hosmer (south)	23	22.37	31.32	5.59	7.83	71.4
Hosmer (southwest)	24	18.99	31.21	4.75	7.80	60.9
Jung	25	26.55	34.27	6.64	8.57	77.5
Bergerson	26	26.80	32.42	6.70	8.11	82.7
Norbeck (N)	27	27.92	35.97	6.98	8.99	77.6
Norbeck (N.E.)	28	28.99	29.95	7.25	7.49	96.8
Norbeck (N.W.)	29	30.72	40.85	7.68	10.21	75.2
Norbeck (W)	30	31.87	37.68	7.97	9.42	84.6

$$* \quad \text{Percentage yield} = \frac{\text{Yield of unphosphated x 100}}{\text{Yield of adequately phosphated}}$$

Table 4. Available P Indexes as Determined by Various Quick Soil Test Methods and Percentage Yield for the 30 Soil Samples

	Procedures						
Sample Number	Bray #1 (1:10)	Bray #1 (1:50)	Water	Olsen (.5N $NaHCO_3$)	Barber (0.3N NaOH +.5N $Na_2C_2O_4$)	Morgan	Percentage Yield
			parts per two million				
1	12	21	1.6	11	19	11	64.5
2	58	73	6.6	42	75	41	89.0
3	37	52	4.8	29	49	32	75.2
4	20	29	1.8	14	28	10	51.1
5	37	55	5.1	24	42	25	76.4
6	42	57	5.2	28	51	45	84.5
7	35	58	3.5	29	53	30	81.2
8	54	69	8.1	38	56	51	77.9
9	43	63	7.2	35	48	13	83.5
10	42	60	5.0	26	61	27	83.8
Mean	38	54	4.9	28	48	29	77.0
11	36	50	7.0	30	47	59	78.7
12	24	36	5.3	24	33	37	81.5
13	30	42	5.9	26	42	25	84.5
14	32	47	6.8	27	49	33	81.5
15	24	39	3.5	20	37	28	88.4
16	32	45	5.3	27	41	48	83.7
17	8	13	1.5	7	9	9	69.8
18	11	20	1.8	11	15	22	79.2
19	22	31	2.6	16	28	13	71.8
20	9	14	2.2	11	11	16	61.4
Mean	23	34	4.2	20	31	29	78.0

Table 4. Continued.

Sample Number	Procedures: Bray #1 (1:10)	Bray #1 (1:50)	Water	Olsen (.5N $NaHCO_3$)	Barber (0.3N NaOH +.5N $Na_2C_2O_4$)	Morgan	Percentage Yield
	parts per two million						
21	71	106	16.3	62	88	90	85.2
22	72	113	13.5	60	93	96	98.4
23	20	42	4.0	24	30	44	71.4
24	11	24	2.6	19	29	11	60.9
25	17	34	2.6	22	42	19	77.5
26	49	83	7.6	38	65	53	82.7
27	24	36	5.9	27	40	47	77.6
28	45	75	7.4	38	65	51	96.8
29	25	46	4.4	23	45	39	75.2
30	41	67	10.7	44	62	50	84.6
Mean	38	63	7.5	36	56	50	81.0

Correlation Between Yield Response and Estimates of Available P

The linear correlation coefficients between the various quick soil test methods for available P and yield responses for all soils are given in Table 5.

Table 5. Linear Correlation Coefficients Between Various Quick Soil Tests for Available P and Percentage Yield

Method Y		Method X	r Value
Percentage	Yield	Bray No. 1 (1:10)	.695**
"	"	Bray No. 2 (1:50)	.709**
"	"	Water	.635**
"	"	Olsen	.688**
"	"	Barber	.725**
"	"	Morgan	.637**

**Significant at .99 level, value needed (.463).

Z Test Between r Values (33)

t = 0.6373 N.S. d. f ∞, N. S. = Non-significant, value needed at 5% level (1.64).

The P obtained with all extractants used was highly correlated with percentage yield. The highest correlation value, however, was obtained with Barber's method. Morgan and water extractants had the lowest r values.

A Z test run on all methods indicated that there was no significant difference between the r values.

The linear correlation coefficients between soil tests and percentage yield grouped according to parent materials are given in Table 6.

The data in Table 6 show that the estimates of available P obtained with all extractants, except Morgan, on residual soils were well correlated with yield responses. However, the relationship between water and yield response was not as close as others. Water was significant at the 5% level with yield response. All extractants gave significant correlation coefficients with yield responses on till soils. The relationships were not as close with water and Morgan extractants. On loess soils all extractants, except water and Morgan's, gave significant correlation coefficients with yield responses at the 5% level. Morgan and water extractants gave nonsignificant correlation coefficients with yield responses.

The Z test indicated that there were no real differences between methods at the same level of significance.

The linear correlation coefficients between soil test methods and yield responses of two textural groups are given in Table 7. The textural groups were obtained by the method of Lunt <u>et al</u>. (24). This relationship was determined to assist in the interpretation of the above results.

Table 6. Linear Correlation Coefficients Between Various Soil Tests for Available P and Yield Responses Grouped According to Parent Materials

Method Y	Method X	Residual Soils	Loess Soils	Till Soils
		r value	r value	r value
Percentage Yield	Bray No. 1 (1:10)	.8037**	.6665*	.8072**
" "	Bray No. 1 (1:50)	.8648	.7386*	.8132**
" "	Water	.7263*	.5682	.6857*
" "	Olsen	.7969**	.6643*	.7691**
" "	Barber	.8371**	.7236*	.8401**
" "	Morgan	.6084	.5275	.7471*

* Significant at .95 level, value needed (.632)
**Significant at .99 level, value needed (.765)

Z Test (33) t = 0.7216 N.S., t = 0.3748 N.S., d.f.∞, value needed at 5% (1.64)
N.S. = Nonsignificant

Table 7. Linear Correlation Coefficients Between Soil Tests and Yield Response of two Textural Groups

Method Y		Method X	Moderately Fine Textured Soils	Medium Textured Soils
			r value	r value
Percentage	Yield	Bray No. 1 (1:10)	.6801**	.7145**
"	"	Bray No. 1 (1:50)	.7136**	
"	"	Water	.6016*	.7003**
"	"	Olsen	.6642**	.7353**
"	"	Barber	.7352**	.7752**
"	"	Morgan	.6384*	.5965*

* Significant at 5% level, value needed (.514)
**Significant at 1% level, value needed (.641)

Z Test (33) t = 0.3865 N.S., d.f. ∞, value needed at 5% (1.64),
N.S. = Nonsignificant

The data in Table 7 show that on moderately fine textured soils, the P obtained with all extractants correlated well with yield responses. However, the P obtained with water and Morgan extractants was not as closely related with yield responses. Both water and Morgan were significant at the 5% level.

On medium textured soils, the P obtained with all extractants, with the exception of Morgan, was highly correlated with yield responses. Morgan, however, correlated with yield response at the 5% level. The test between r values indicated that there were no significant differences between methods at the same level of significance.

The linear correlation coefficients between soil test methods and yield responses grouped according to pH ranges are given in Table 8. Twenty-one soils had a pH of 7 or less and nine soils had a pH > 7.

Table 8. Linear Correlation Coefficients Between Soil Tests and Yield Response Grouped According to pH Ranges

Method Y	Method X	pH of Soils+ pH 6-7	pH>7
		r value	r value
Percentage Yield	Bray No. 1 (1:10)	.7328**	.7180*
" "	Bray No. 1 (1:50)	.7568**	.6084
" "	Water	.6425**	.7256*
" "	Olsen	.7106**	.6933*
" "	Barber	.7814**	.6663*
" "	Morgan	.6506**	.5288
		21	9

* Significantly different from zero at 5% level, value needed, (.666)
**Significantly different from zero at 1% level, value needed, (.549)
\+ pH 6-7, 21 pairs of observations, pH>7, 9 pairs of observations.

Z Test of Significance Between r Values (33)
t = 0.743 N.S., d.f.∞, value needed at 5% level, (1.64)
N.S. = Nonsignificant

The data in Table 8 show that highly significant correlations were obtained between available P extracted by all methods and yield responses on soils with a pH range of 6-7. The highest correlation coefficient value was obtained with Barber's extractant, with water having the lowest r value. Also, on soils with pH>7, all extractants, with the exception of Bray No. 1 with soil to solution ratio of 1 to 50, and Morgan, gave significant correlation coefficient with yield responses at the 5% level. Z test between methods, however, showed that there was no significant difference between methods at the same level of significance.

Quick P Uptake Experiment

Phosphorus uptake by plants is given in Table 9. The total phosphorus uptake was calculated on the basis of thirty seedlings per pot and was obtained by multiplying the yields on dry matter basis with the percent P in the plant tissue. The figures given in Table 9 are the averages of five replications and are in milligrams of phosphorus found in 30 plants.

Table 9. Plant Uptake of P in Milligrams of P per Carton, Plants Grown on Experimental Soil for 7 Days

	Sample No.	Plant Uptake mg P/Carton
Residual	1	3.50
	2	3.57
	3	3.57
	4	3.44
	5	3.41
	6	3.51
	7	3.37
	8	3.77
	9	3.58
	10	3.39
	Mean	3.49
Loess	11	3.48
	12	3.49
	13	3.31
	14	3.44
	15	3.68
	16	3.50
	17	3.28
	18	3.41
	19	3.22
	20	3.26
	Mean	3.41
Till	21	4.08
	22	3.85
	23	3.13
	24	3.37
	25	3.32
	26	3.46
	27	3.35
	28	3.40
	29	3.48
	30	3.81
	Mean	3.53

As indicated in Table 9, appreciable amounts of P were absorbed by the seedlings during the seven day growth period on the soil. More absorption was discernible in soils with higher available P indexes as determined by various quick soil test methods.

Correlation Between P Uptake and Plant Available P

The linear correlation coefficients between soil tests and phosphorus uptake are given in Table 10. Thirty samples from thirty sites were involved in the correlation data.

Table 10. Linear Correlation Coefficients Between Plant Uptake of P and Available P Obtained with Quick Soil Tests on All Sites

30

Method Y	Method X	r Value
Uptake	Bray No. 1 (1:10)	.7127**
"	Bray No. 1 (1:50)	.6952**
"	Water	.7925**
"	Olsen	.7478**
"	Barber	.7367**
"	Morgan	.6583**

**Significantly different from zero at 1% level, value needed (.463)

Z Test Between r Values (33)

t = 1.02 N.S., d.f.∞, N.S. = Nonsignificant, value needed, (1.64).

The P obtained with all extractants was highly correlated with plant uptake of P. The highest correlation coefficient value was obtained between water and plant uptake of P. The lowest r value was obtained with Morgan's extractant. However, the test between methods indicates that there was no significant difference between the r values obtained with the various quick soil test methods.

The linear correlation coefficients between soil tests and plant uptake of P grouped according to parent materials are given in Table 11.

As indicated in Table 11, the estimates of available P obtained on residual soils with all extractants, except water and Barber, gave non-significant correlation with plant uptake of P. However, the estimates of available P obtained with Barber's extractant were not as well correlated with plant uptake of P as were water. About 80* percent of the variation in uptake of P could be accounted for by water. On loess soils, Morgan's extractant was the only one that correlated with uptake of P.

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*The percentage used here, and throughout the discussion, was obtained by multiplying r^2 by 100 = coefficient of determination.

Table 11. Linear Correlation Coefficients Between Plant Uptake of P and Available P Indexes Obtained with Various Extractants Used on Three Parent Materials

Method Y	Method X	Residual Soils	Loess Soils	Till Soils
		r value	r value	r value
P Uptake	Bray No. 1 (1:10)	.4769	.4903	.8236**
" "	Bray No. 1 (1:50)	.3563	.5709	.7836**
" "	Water	.9004**	.4288	.9210**
" "	Olsen	.5030	.5314	.9147**
" "	Barber	.6448*	.5610	.8498**
" "	Morgan	.4500	.6789*	.7513*

* Significant at .95 level, value needed (.632)
**Significant at .99 level, value needed (.765)

Test Between r Values Z Test (33) t = 1.017 N.S., d.f.∞, N.S. = Nonsignificant, value needed at 5% level (∞.64)

On the other hand, the estimates of available P obtained with all extractants on till soils correlated well with plant uptake of P. The relationship, however, was not as close with Morgan extractant.

The test between methods indicated that there was no significant difference between methods at the same level of significance.

The linear correlation coefficients between soil test methods and plant uptake of P subdivided according to textural groups are given in Table 12. The textural classes were determined by the method of Lunt _et al_. (24). Since the textural classes were quite close, only two meaningful textural groups were possible; namely, moderately fine textured soils, and medium textured soils.

Table 12. Linear Correlation Between Soil Tests and Plant Uptake of P Subdivided According to Textural Groups

Method Y	Method X	Textural Groups+ Moderately Fine Textured Soils	Medium Textured Soils
		r value	r value
P Uptake	Bray No. 1 (1:10)	.7053**	.6333*
" "	Bray No. 1 (1:50)	.5939**	.5964*
" "	Water	.8513**	.5927*
" "	Olsen	.7852**	.5940*
" "	Barber	.7071**	.4979

* Significant at .95 level, value needed (.514)
**Significant at .99 level, value needed (.641)
\+ Fine textured soils, 15 observations; medium textured soils, 15 observations.

Z Test - Test Between r Values (33) t = 1.000 N.S., d.f.∞
N.S. = Nonsignificant, value needed (1.64)

The estimates of available P obtained with all extractants on moderately fine textured soils gave highly significant correlation with plant uptake of P. The highest correlation coefficient values were obtained with water and Olsen extractants. Bray No. 1 (1:10), Bray No. 1 (1:50), and Morgan extractants had about the same r values. On medium textured soils, significant correlations were obtained between all extractants and plant uptake of P, with the exception of Morgan's extract. The relationships, however, were not as close as those obtained for moderately fine textured soils. The test between methods indicated that there were no real differences between methods at the same level of significance.

The linear correlation coefficients between estimates of available P and plant uptake of P grouped according to pH ranges are given in Table 13. On the whole, twenty-one soils had a pH of 6 to 7. Nine soils had a pH>7.

On soils with a pH range of 6 to 7, the available P indexes obtained with all extractants were highly correlated with plant uptake of P. The highest correlation coefficient values were obtained with water and Olsen extractants. However, the test between r values showed that there were no real differences between methods at the same level of significance.

On the other hand, the P obtained with all extractants from soils with a pH>7, did not correlate with plant uptake of P.

Table 13. Linear Correlation Between Soil Tests and Plant Uptake of P Grouped According to pH Ranges

Method Y	Method X	pH 6-7	pH 7
		r value	r value
P Uptake	Bray No. 1 (1:10)	.7316**	.1305
" "	Bray No. 1 (1:50)	.7384**	.0772
" "	Water	.8379**	.0568
" "	Olsen	.8117**	.0496
" "	Barber	.7537**	.0794
" "	Morgan	.7132**	.0681

**Significant at .99 level, value needed (.549)

Z Test - Test Between r Values (33) t = 1.002 N.S., d.f.∞, N.S. = Nonsignificant, value needed (1.64)

The linear correlation coefficients for the comparison between the various quick soil test methods are given in Table 14.

As indicated in Table 14, the available P indexes obtained with all extractants were highly correlated between methods. The correlation coefficients obtained between Bray No. 1 with a soil to solution ratio of 1 to 10, 1 to 50, and Barber, on one hand, and water and Morgan on the other hand, were not as high as those between other methods.

Tests of significance between the r values indicated that the r values obtained between the Bray No. 1 methods, Bray No. 1 and Olsen, Bray No. 1 and Barber, and Olsen and Barber, were significantly better than the r values obtained with Bray No. 1 and Morgan, and Barber and Morgan. No significant differences were observed between other r values.

Table 14. Linear Correlation Coefficients for the Comparison Between the Quick Soil Test Methods

	Bray No. 1 (1:10)	Bray No. 1 (1:50)	Water	Olsen	Barber	Morgan
			r value			
Bray No. 1 (1:10)		.9729**	.8778**	.9296**	.9523**	.8527**
Bray No. 1 (1:50)			.8945**	.9594**	.9661**	.8383**
Water				.9568**	.8624**	.8734**
Olsen					.9491**	.8638**
Barber						.8375**

**Significant at the .99 level, value needed (.463)

Z Test - Test of Significance Between r Values

	t	d.f.
Bray No. 1 (1:10) and (1:50) vs. Barber and Morgan	3.202**	∞
Bray No. 1 (1:10) and (1:50) vs. Bray No. 1 (1:10) and Morgan	2.536**	∞
Bray No. 1 (1:10) and Olsen vs. Barber and Morgan	1.692*	∞
Bray No. 1 (1:10) and Olsen vs. Bray No. 1 (1:10) and Morgan	1.492 N.S.	∞

* Significant at .95 level, value needed (1.64)
**Significant at .99 level, value needed (2.33)
N.S. = Nonsignificant

Correlation Between Quick Uptake of P and Yield Response

The linear correlation coefficient for the correlation between quick uptake of P and yield response is given in Table 15. The purpose of this correlation was to determine the relationship, if any, between the uptake of P obtained with quick uptake experiment and yield response obtained with yield response experiment.

Table 15. Linear Correlation Coefficient Between Quick Uptake of P and Yield Response

Method X	Method Y	r Value
Quick uptake of P	% Yield	.5112**

** Significant at .99 level, value needed (.463)

As indicated above, the quick uptake of P obtained with the quick uptake experiment correlated well with the yield response obtained with the yield response experiment. If one considers quick uptake as a soil test the correlation here is poorer than any of the soil test methods. See Table 5.

DISCUSSION

Correlation Between Yield Responses and Estimates of Available P

The estimates of available P obtained with all extractants as indicated in Table 5 gave highly significant correlation with yield responses. Also, the tests between the r values indicated that there were no significant differences between the methods. However, the highest r value was obtained with Barber's method.

Bray No. 1 with a soil to solution ratio of 1 to 50 gave a higher correlation coefficient with yield responses than Bray No. 1 with a soil to solution ratio of 1 to 10, Olsen, Morgan and water extractants. Bray No. 1 with a soil to solution ratio of 1 to 10, and Olsen gave about the same relationship with yield responses. Also, Morgan and water extractants had about the same correlation coefficient values with yield responses.

The variation in the r values may be partly explained by the fact that these extractants are known to extract variable amounts of the different forms of P in the soils. All the extractants used, with the exception of Morgan and water are known to extract Al and Fe- forms as well as other forms of P (1, 6, 13). Ghani and Aleem (19) have shown that Morgan's method extracts mono-, di-, and tricalcium phosphates. The fact that the r values obtained between Bray No. 1 and Olsen, and Bray No. 1 and Barber, are significantly better than Bray No. 1 and Morgan, and Barber and Morgan, seems to suggest that they are better estimates of plant available P. The fact that water P was like Morgan but with a lower r value, seems to suggest that water P does notconsist solely of calcium phosphate (13).

Grouped according to parent materials, the results in Table 6 have indicated that about 64% of the variation in yield responses could be accounted for by Bray No. 1, Olsen and Barber extractants on residual and till soils. Also, over 70% of the variation in yield responses could be accounted for by Bray No. 1 with a soil to solution ratio of 1 to 50, and Barber extractants on residual and till soils. However, tests between the r values indicated that there were no real differences between methods at the same level of significance.

On loess soils only 51% of the variation in yield responses could be accounted for by Bray No. 1 with a soil to solution ratio of 1 to 50, and Barber extractants.

The data in Table 8 showed that on soils with a pH>7, a lower correlation coefficient was obtained between estimates of available P and yield response. Also, the data in Table 2 indicated that five of the nine soils with a pH>7 were loess soils. It would appear therefore, that the rather low correlation for loess soils may in part be related to pH. Texture, however, does not seem to have had much effect, as shown in Table 7. As indicated above, about 70% of the variation in yield response could be accounted for by Bray No. 1 with soil to solution ratio of 1 to 50, and Barber extractants on residual and till soils and only 51% of the variation could be accounted for on loess soils. But the data in Table 4 indicated that on the average, yield responses were about the same on residual and loess soils. This poses a problem which needs additional research.

On all soils, over 52% of the variation in yield response could be accounted for by Barber's extractant and less percentage for other extractants. Therefore, it would appear that either the extractants were extracting more than just the plant available forms of P or that the soils were fairly low in plant available forms of P. Bray and Dickman (10) showed that fractions 1 and 2 of the adsorbed phosphates were important for plant response. High amounts of these fractions would result in low response. It would appear from Table 4 that the soils were not very low in the plant available forms of P, otherwise tremendous responses could have been obtained. Some responses were obtained, however, and therefore it would appear that the extractants were extracting more P than plant available P.

0.3N NaOH + 0.5N $Na_2C_2O_4$ proposed by Barber (2) gave a consistently higher r value with yield responses and was particularly good for soils with a pH between 6-7. This is contrary to the results of Barber et. al. (2) who found the method to be particularly useful for soils with a pH>7.

Correlation Between Plant Uptake of P (Using Quick Uptake Method) and Estimates of Available P

As shown in Table 10, the estimates of available P obtained with all extractants were highly significantly correlated with plant uptake of P. The tests between the r values also indicated that there were no real differences between the methods. However, water gave the highest correlation coefficient value with uptake of P.

Olsen (29) gave a slightly higher r value with plant uptake of P than Bray No. 1 and Morgan. Morgan gave the lowest r value with uptake of P.

The variation in the r values may be attributable to the proportions of the available P extracted and the forms of P available to plants in the soil.

Bishop and Barber (4) have demonstrated that the correlation between uptake of P and plant available P could be influenced by the forms of P compounds in the soils. Availability of P to plants is a function of the forms of P compounds present in the soil.

As indicated in Table 11, about 83% of the plant uptake of P could be accounted for by water on both residual and till soils. A similar trend was observed with Olsen extractant on till soils. Other extractants, with the exception of Morgan, accounted for about 64% of the variation in the uptake of P. Morgan accounted for just over 56% of the variation in uptake of P.

The low correlation coefficient values obtained for residual and loess soils may in part be explained on the basis of texture and pH. Additional data would be necessary to fully explain how texture and pH could have caused the rather poor correlation obtained for methods on both residual and loess soils.

However, the data in Table 12 indicated that lower correlation coefficients were obtained between the P obtained with the extractants and uptake of P on medium textured soils. Also, the data in Table 2 indicated that nine of ten loess soils and five of the ten residual soils were medium textured soils. This seems to point to the fact that texture may in part be related to the low correlation obtained for loess and residual soils.

The data in Table 2 indicate that five of the loess soils and two of the residual soils had a pH>7. The data in Table 13 indicated that an extremely poor relationship existed between the estimates of available P obtained with all extractants and uptake of P on soils with a pH>7. It would appear, therefore, that the low correlation on loess soils may in part be related to pH.

On the average, more P was absorbed from till and residual soils than from loess soils. This seems to follow the same trends as the estimates of available P extracted with the methods. Also, there was good evidence of good root proliferation in the test soils(see Fig. 4) and adequate supply of other nutrients and moisture.

This seems to point to the fact that the low correlation in residual and loess soils may be related in part to pH and texture. Additional research, however, may be necessary to show the "cause and effect" of pH and texture.

Correlation Between Quick Uptake of P and Yield Response

The data in Table 15 show that about 25% of the variation in yield response could be accounted for by quick uptake of P. It would appear, therefore, that very little relationship exists between the quick uptake of P obtained with the quick uptake experiment and yield response obtained with the yield response experiment.

This explains the different results obtained with the yield response experiment and the quick uptake experiment.

SUMMARY AND CONCLUSIONS

The estimates of available P obtained with five different extractant solutions were correlated with yield response and uptake of P using barley as a test crop.

The results from yield response studies indicated that yield responses were, on the average, lower in soils with higher estimates of available P as determined with the extractants.

All methods were found to correlate well with yield responses on all soils. Grouped according to parent materials, however, Bray No. 1, Olsen, and Barber were found to be superior to water and Morgan extractants. Although no significant differences were found between methods at the same level of significance, Bray No. 1 with a soil to solution ratio of 1 to 50, and Barber extractants were found to account for over 64% of the variation in yield response on residual and till soils, and 51% on loess soils. Other extractants were found to be lower.

The data from quick uptake studies indicated that all the extractants were good estimates of available P for all soils.

Grouped according to parent materials, water and Barber extractants were found to have higher r values than other extractants on residual soils. All the other extractants used, were found to have higher r values than Morgan on till soils. However, on loess soils, Morgan extractant was found to have a higher r value than other extractants. Water and Olsen extractants accounted for over 80% of the variation in uptake of P on till soils, and water accounted for over 80% of the variation on residual soils.

The results also seem to point to the fact that pH and texture influence P uptake and pH alone influences yield response correlations. Additional research, however, is necessary to show how these factors influence the variables.

The correlation between quick uptake of P and yield response indicated that only 25% of the variation in yield response could be accounted for by quick uptake of P. Therefore, it would seem that the two experiments were not related.

From the data on yield response and quick uptake of P, it would appear that a need arises to consider the use of a different extractant on loess soils. The differences between the coefficients of determination for residual and till soils on one hand, and loess soils on the other hand, are fairly great to consider the use of different extractants, one for residual and till soils, and the same or another for loess soils.

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